Journal of Cleaner Production 176 (2018) 119–129

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Experimental investigation of the passive cooled free-standing photovoltaic panel with fixed aluminum fins on the backside surface

Filip Grubišić-Čabo [a], Sandro Nižetić [a, *], Duje Čoko [b], Ivo Marinić Kragić [c], Agis Papadopoulos [d]

[a] *LTEF- Laboratory for Thermodynamics and Energy Efficiency, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Rudjera Boskovica 32, 21000 Split, Croatia*
[b] *Department of Electronics, Faculty of Electrical and Mechanical Engineering and Naval Architecture, University of Split, Rudjera Boskovica 32, 21000 Split, Croatia*
[c] *Laboratory of Numerical Modeling and Computer Application, Faculty of Electrical and Mechanical Engineering and Naval Architecture, University of Split, Rudjera Boskovica 32, 21000 Split, Croatia*
[d] *Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki, GR-54124, Thessaloniki, Greece*

ARTICLE INFO

Article history:

Keywords:
Photovoltaics
Renewable energy
Efficiency
Experimental investigation
Passive cooling

ABSTRACT

This paper deals with a passive cooling technique for photovoltaic (PV) panels in order to increase energy conversion efficiency through a reduced PV panel operating temperature. The proposed passive cooling technique consists of aluminum fins mounted with epoxy conductive glue on the backside surface of the PV panel (Si-poly, 50 W panel examined). Two specific rib configurations, i.e. geometries were considered in order to enhance the cooling rate from the backside surface of PV panel. The first configuration was obtained from parallel positioned aluminum fins (L-profile), while the second configuration was obtained from randomly positioned perforated L profiles. The first approach was found to be less efficient than the second one, so it was not further analysed. Main issue with the first configuration was related to its low efficiency improvement during periods of lower solar irradiation levels. The second approach, i.e. the modified geometry showed better performance response throughout the insolation spectrum, averaging about 2% in efficiency improvement relative to the total power output for the specific obtained measurement period. Further, with the specific rib geometry proposed, a more intense cooling rate was achieved. Measurements were obtained in November for a geographical location of City of Split, coast side of Croatia. The presented results in this study are useful as they provide deeper insight into the heat transfer phenomena, i.e. the general influence of a passive cooling technique with wind gusts and the limitations it brings. The examined cooling technique showed potential; however, it should be tested on a PV system with a longer measurement period in order to be able to get more precise results, which include longer periods of typical season weather and which could be also useful to determine potential effect of the cooling technique on the PV panel operating lifetime. The main benefit of the proposed passive cooling technique is reflected through more efficient PV systems, and potential increase of the lifetime of PV panels, by lowering their operating temperature.

1. Introduction

Photovoltaic technology is nowadays widely implemented and it certainly could help to reach general energy sustainability related goals (Čuček et al., 2016). The majority of installed photovoltaic (PV) systems are based on silicon (Si-PV) technology (Corcelli et al., 2017) which is the oldest technology but currently the most economically viable. According to Fraunhofer ISE (ise.fraunhofer, 2017), the overall market share of Si based PV technologies was 94% in 2016. The previous fact just supports the thesis that in upcoming years, Si based PV technology will still dominate the market. Any effort to improve the widely used Si based PV technology is crucial and important.

The major concern with Si-PV technology is the degradation of electrical efficiency when the PV panel is exposed to elevated operating temperatures. On average, the degradation ranges from

---

* Corresponding author.
E-mail address: snizetic@fesb.hr (S. Nižetić).

https://doi.org/10.1016/j.jclepro.2017.12.149

about 0.25%/°C to about 0.5%/°C (Nižetić et al., 2016), depending from the specific PV technology, and manufacturing quality of the PV modules. Basically, in periods of highest solar irradiation levels, the photovoltaic energy conversion efficiency is the lowest, due to higher PV panel operating temperatures. By increasing the quantity of delivered electricity from the PV systems, through an efficient and economical utilization of the cooling technique, CO_2 emissions can be indirectly reduced. Additionally, total lifetime of a PV panel can also be prolonged by applying the cooling techniques (Royo et al., 2016) which is also an important advantage.

PV panel operating temperatures can be reduced with the application of specific cooling techniques and which can be divided into passive and active cooling techniques. The main goal of cooling techniques is to efficiently remove any excess heat from the PV panel and by that enhance the panel's electrical efficiency. With passive techniques, dissipated heat in the majority of cases is rejected into the environment. However, in the case of active cooling techniques, the utilization of waste heat should be considered as it is crucial for the economic viability of the specific examined cooling technique. The usual technical way to utilize waste heat from PV panels is through photovoltaic-thermal, i.e. PV/T systems (Lamnatou and Chemisana, 2017). Passive cooling techniques for PV applications are in general less complicated and with lower initial investments when compared to active cooling techniques, (Grubišić-Čabo et al., 2016; Elbreki et al., 2017). On the other side, they are less efficient than active cooling techniques but do not require additional energy for the cooling system's operation as it is the case for active cooling techniques.

Passive cooling techniques have intensively been examined in last decades in order to find acceptable cooling strategies from both performance and economic points of view. In a recently obtained comprehensive analysis of passive cooling techniques for PVs (Nižetić et al., 2017) it was found that there is a gap in the existing literature related to the economic and environmental aspects of passive cooling techniques. Broadband optical thin-film filters were examined in (Kecebas et al., 2017) for passive radiative cooling. The authors found that with the application of the previously mentioned optical filters, it was possible to boost the average reflectance in the visible and near-infrared spectrums by 3–4% (which increases the cooling rate by about 35 W/m^2). Rooftop integrated photovoltaic applications were analysed from a passive cooling aspect in (Mittelman et al., 2009) where different channel geometries, i.e. channel spacing and length were analysed with a numerical approach. It was found that an increase in channel spacing will cause an increase in the energy efficiency conversion from about 0.3% to 0.5%. The application of phase change materials (PCM) for the passive cooling of PVs is most investigated when analysing existing literature data. The application of PCM materials for the passive cooling of the PV-PCM systems was analysed in (Stropnik and Stritih, 2016) by applying numerical and experimental approaches. They found that with the application of a RT28CH PCM material, the peak PV cell temperature was reduced by about 35.6 °C when compared to the referent non-cooled PV panel. Yellow petroleum jelly was considered in (Indartono et al., 2016) for the improvement of photovoltaic performance and it turned out to be an efficient option. A global analysis related to the implementation of PV-PCM based cooling was obtained in (Smith et al., 2014). The authors found that the average efficiency improvement of PV-PCM systems ranges from 2% to 6%, depending from the specific geographical location. A passive cooling technique as a combination of fin and cotton wick structures was proposed and experimentally tested in (Chandrasekar and Senthilkumar, 2016). They found improvement in delivered electricity by about 14% with a reduction in PV panel operating temperatures of 12%. A water immersion method was proposed and experimentally checked in (Rosa-Clot et al., 2010) where an average increase of 11% in efficiency was found. They also found that the optimal depth of the water layer is between 2 cm and 4 cm in thickness. The passive cooling of a PV cell with the application of backside mounted fins was analysed in (Cuce et al., 2011). The improvement of the peak power output was about 20% on average and an efficiency improvement of between 4.0% and 4.7% was reached (however, the authors examined a very small PV cell of just a few watts in laboratory conditions when analysing the reported performance data). The pork fat as the potential PCM material for PV-PCM cooling was analysed in Nižetić et al. (2018) and it was found that pork fat has got almost similar characteristics when compared to other PCM materials but it is much more reasonable from the economic point of view.

From the previous brief elaboration of the latest research findings, it can be concluded that we have different examined passive cooling strategies (different heat sink elements that are usually applied on the backside surface of the PV panel). From all the considered passive cooling options, the most economically viable option is air-cooling as well as most favourable from an environmental point of view (Nižetić et al., 2016). For that reason, this study was focused on passive cooling solutions that consider cooling with surrounding air.

The main objective of this paper was to examine the performance potential of the proposed passive cooling technique for photovoltaic panels by experimental means (i.e. proof of concept). Two different aluminium rib configurations, i.e. geometries were considered and PV panel performance response was elaborated. The novelty of the paper is the introduction of control panel in realistic operating conditions, whose power output is used as a referent data. That way, it can be concluded with great accuracy that applied passive cooling technique really results in greater electrical efficiency, and that increase in efficiency in realistic conditions is not result of higher irradiance, angle of irradiance or sudden atmospheric changes. Also, results of other passive cooling experiments are obtained in laboratory conditions, or without control panel. In this study, a direct confirmation of electric efficiency raise is presented.

2. Peak power yield difference

During the experimental setup phase, a new issue was opened; how to prove the passive cooling effect in realistic conditions. When laboratory conditions are in place (wind velocity and insolation) it is fairly easy to diagnose the raise in electrical efficiency. However, in realistic conditions, comparing the results from two different days, or even two different periods of day proves to be a challenge. From here on, insolation will be considered total solar irradiation that reached the surface of the PV. In order to overcome this obstacle, a referent photovoltaic panel is introduced. A referent panel is a panel without the modification which is used for comparison with modified panel, before and after the modification. That way, it can be directly shown that raise in electrical efficiency is a consequence of modification, regardless of the change in realistic conditions. In this study, referent panel is called Panel A, while tested panel (which will be modified later on) is called Panel B. The measuring equipment measures both panels simultaneously, when activated. After voltage-current characteristics of both panels are measured, peak power yield, P_A and P_B of both panels A and B is calculated. Peak power yield difference is defined as

$$\Delta P = P_A - P_B \tag{1}$$

and it literally says which panel gives more power for identical operating conditions. Peak power yield difference can also be